

**PHENOMENOLOGICAL STUDIES OF SOME
HADRONIC REACTIONS
MOSTLY HADRON-NUCLEUS COLLISIONS**

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The main part of this thesis concerns hadron-nucleus interactions. The problem is to explain what happens when a high energy particle traverses a nucleus and what kind of processes that govern the emittance of the observed particles. We use data from proton-emulsion collisions at energies 67-400 GeV and hadron (π or p)-nucleus (Cu or Pb) reactions at 50-150 GeV for some phenomenological investigations of these problems. We present a method to extract the leading baryon pseudorapidity distribution in proton-emulsion collisions. Further we find for proton-emulsion collisions that the increase of the shower particle multiplicity with increasing energy is explained merely by the widening of the available pseudorapidity region. We have extracted the pseudorapidity distributions of the shower particles as a function of how many nucleons in the nucleus that are primarily affected by the incoming projectile. The results fit very well into the scheme of an independent soft-collision model with short range correlations in rapidity. We also present a phenomenological model for leptonproduction on nuclei. We compare with experimental data and make some predictions for neutrino scattering on nuclei. The second part is an analysis of the low-energy πK-scattering using dispersion relations, where we present solutions of the scattering amplitudes that are consistent with crossing and unitarity.			
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- I. Properties of the Leading Particle in Proton-Nucleus Interactions.
Physica Scripta 18 (1978) 304
(Together with B. Andersson, I. Otterlund and E. Friedländer)
- II. Nuclear Interactions of 400 GeV Protons in Emulsion.
Nucl. Phys. B142 (1978) 445
(The International Emulsion Collaboration)
- III. The Energy Independence of Proton-Emulsion Collisions.
Nucl. Phys. B153 (1979) 493
(Together with B. Andersson and I. Otterlund)
- IV. A Phenomenological Model for Nuclear Leptoproduction.
Phys. Lett. 83B (1979) 379
(Together with B. Andersson and G. Gustafson)
- V. A Calculation of ν -Distributions in Hadron-Nucleus Interactions.
Lund preprint LU TP 80-9 (To be published)
(Together with E. Stenlund)
- VI. A Phenomenological investigation of the Shower Particle Pseudorapidity Fluctuations in Hadron-Nucleus Collisions.
Lund preprint LU TP 80-10 (To be published)
(Together with B. Andersson and I. Otterlund)
- VII. An Analysis of Low-Energy π K-Scattering.
Il Nuovo Cimento 43A (1978) 376
(Together with N. Johannesson)



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INTRODUCTION

Everything revealed by nature concerning high energy physics stems from the results of experiments where accelerated particles are made to collide. The interactions at play are nowadays usually described as being of three different kinds: Gravitation (negligible in high energy physics), Electroweak (the unification of weak and electromagnetic interaction, the theory of which has won a Nobel Prize) and Strong (with many problems yet to be solved). It is the latter interaction that is of interest in this thesis. A complete theory for the strong interaction does not exist, but up to now QCD (Quantum Chromodynamics) is the best candidate.

In this thesis we have chosen a phenomenological approach: Use the results of experiment to gain more understanding of the fundamental processes involved. The first and main part (paper I-VI) concerns particle-nucleus interactions at very high energies, where the particle is either a hadron or a lepton. The collision of a high energy particle and a nucleus is a very complicated process which involves many degrees of freedom. Many particles are created and recoiling nucleons are kicked out of the nucleus. Usually the collision ends up with the nucleus boiling off heavy fragments of nuclear matter.

Most of the experiments performed in high energy physics are particle-particle experiments, the intention of which is to investigate the interplay between two particles (hadrons, leptons) or eventually between the constituents of hadronic matter (quarks and gluons). Why then study the much more complicated particle-nucleus interaction? There are mainly two reasons. One is the prospect to find new fields of physics, e.g. collective phenomena in hadronic matter. The other is the possibility to study the space-time development of a particle when it traverses a nucleus with the disturbed nuclear matter as an indirect detector. The relatively low average number of observed produced particles in hadron-nucleus collisions rules

out a simple intranuclear-cascade model, where the incident particle collides with a few nucleons and every subcollision gives instantaneously new particles which give rise to new collisions. This cascading predicts many more particles than are actually observed. Thus there must be a timescale for the disturbed nuclear matter to materialize into hadrons. This development is impossible to observe in a particle-particle experiment.

The kind of phenomenology performed in this thesis requires good communications with experimental physics. The close cooperation with the Department of Cosmic and Subatomic Physics in Lund has given me the opportunity to work with two different sets of data, proton-emulsion collisions (International Emulsion Collaboration) and hadron-nucleus collisions from the Heidelberg-Lund experiment performed at CERN. Another need is a good computer that can handle the necessary calculations and analysis of the experimental data.

What happens when a hadron collides with a nucleus? Many different theories exist and most of them are consistent with the present data. Our main aim with this thesis (paper I-III, VI) has been to find new approaches to the datasets and thereby eventually be able to discriminate between the existing models. The experimental information from a hadron-nucleus collision in our data contains the total number of shower particles (n_s) and their individual emission angles (θ or the pseudorapidity variable $\eta = -\ln(\tan(\theta/2))$), the number of grey particles (N_g), and, for the emulsion data, the number of black particles (N_b). A shower particle is defined as a particle with a velocity greater than 70% of the velocity of light. These are mainly pions that are created in the collision. The grey particles which are believed to be mostly recoil protons are defined to have velocities in the range 30 to 70% of the velocity of light. In the emulsion data one also sees black particles, i.e. the low energy particles resulting from the nuclear boiloff after the collision.

The second part of this thesis (paper VII) also reflects the lack of a theory for the strong interaction. Predictions from field theory such as analyticity, crossing and unitarity imply restrictions on the scattering amplitudes. This is used in our analysis of the low-energy behaviour of pion-kaon scattering.

SUMMARY OF PAPERS

In paper I we assume that in a proton-nucleus collision there exists a leading particle effect, which means that a baryon is emitted close to the direction of the incoming proton. We present a method to extract the pseudorapidity distribution of this baryon from the proton-emulsion data. Our results indicate that approximately 50% of the leading baryons are neutrons, which means that the traversing proton completely loses its isospin (charge) information. The comparisons with proton-proton data show that the inelasticity is much larger in a proton-nucleus collision and that the produced pions in the forward direction are unaffected by the nuclear parameters.

Paper II presents the data from the International Emulsion Collaboration experiment where emulsion plates have been exposed to the 400 GeV proton-beam at FNAL. The shower particle pseudorapidity distributions are explored further in paper III. We compare with the results from proton-emulsion collisions at 67, 200 and 300 GeV and we find that the increase in the multiplicity of the shower particles with increasing projectile energy can be explained by the widening of the available central rapidity region. This is true in the energy range 200-400 GeV and holds also if the material is divided into different bins according to the number of heavy prongs, N_h ($N_h = N_g + N_b$), a measure of how violent (central) the collision has been. The shower particle multiplicity in the projectile fragmentation region is independent of energy and N_h , and in the target fragmentation region there is a linear rise with N_h but still no energy dependence.

The topic of paper IV is leptonproduction on nuclear targets. We present a phenomenological model in which the mediating virtual photon gives its momentum to a quark in the nucleus. The quark traverses the nucleus and eventually interacts with the nucleons in the nucleus before it fragments into hadrons. We further assume that the quark loses energy in every interaction according to an analogy with deep inelastic lepton scattering. This gives the attenuation with atomic number of produced particles in the forward direction. The results from the model are compared to experimental data and some predictions are made for neutrino scattering on nuclear targets.

In papers IV and VI we need the probabilities for the traversing particle to collide with a certain number of nucleons in the target. We have made a Monte Carlo program to calculate this distribution (paper V). A nucleus is created according to a Wood-Saxon density distribution. This nucleus is then bombarded with a hadron. We define a nucleon to be hit if the closest distance between the traversing hadron and the nucleon is less than a value depending on the hadron-nucleon cross section.

In paper VI we use the data from the Heidelberg-Lund experiment. This is a counter experiment and therefore we gain a lot by having about 10^3 times more events than in the proton-emulsion data, but there are new problems in the determination of what kind of particle is seen (grey or shower), acceptance and a variety of correction factors. In the emulsion experiment the solid angle acceptance is 4π and one is able to see all the tracks. Another advantage in the Heidelberg-Lund data is that the target is known (Cu or Pb), while the emulsion is a mixture of light (C, N, O) and heavy nuclei (Ag, Br).

In the paper we determine the pseudorapidity shower particle distribution as a function of ν , the number of nucleons that are primarily affected by the projectile. We also get for a given pseudorapidity the fluctuations of the number of particles.

Assuming that the grey particles are recoil protons, originating from the ν nucleons that are hit and also from the elastic nucleon cascade produced by these nucleons, we know the correlation of ν and N_g . For every ring of counters (pseudorapidity interval) in the experimental setup we assume that for each ν the number of shower particles are distributed according to a given probability distribution. We use the average number of particles, one for every ν , as parameters and we have made a fit to the experimental $N_g - n_s(\eta)$ -distributions. We find that Poisson-distributions reproduce the data quite well except for some intervals that need a somewhat broader distribution and the very forward direction where a narrower distribution is needed. The ν -dependence of the average number of shower particles fits very well into the scheme of an independent soft-collision model with short range correlations in rapidity. Every new collision contributes with a constant number of particles in the target fragmentation and the backward central region ($\eta \lesssim 2$). The forward central region gives gradually a saturation for higher ν -values and in the projectile fragmentation region the produced number of shower particles stays constant, independent of ν . One result that is hard to interpret is that the total number of shower particles for one collision is small compared to higher ν -values. This is not compatible with any theoretical model. We believe that there might be a certain amount of diffractive-like peripheral events that contributes to the distributions for only one collision.

Paper VII is a compilation of the πK -scattering amplitude using dispersion relations consistent with crossing, unitarity and the t -channel information. We present different solutions and give comparisons with existing data.

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